FAST GROWING TREE SPECIES IN AGROFORESTRY SYSTEMS: SOIL, TREE GROWTH AND UNDERSTORY BIODIVERSITY

Rodríguez-Rigueiro FJ[1], Ferreiro-Domínguez N[1, 2], Rigueiro-Rodríguez A[1], Mosquera-Losada MR[1*]

(1) Department of Crop Production and Engineering Projects, Escuela Politécnica Superior de Lugo, University of Santiago de Compostela, Campus Universitario s/n, 27002 Lugo, Spain (2) Forest Research Centre, School of Agriculture, University of Lisbon, Tapada da Ajuda s/n, 1349-017 Lisbon, Portugal

*Corresponding author: mrosa.mosquera.losada@usc.es

Abstract

In Galicia (NW Spain) the productivity of the silvopastoral systems can be limited by the high soil acidity, which decreases the availability of nutrients to the pasture and trees. Liming and fertilisation with sewage sludge could improve the soil fertility, favouring the tree growth and the establishment of sowing pasture species in the understory. The aim of this study was to evaluate the effect of liming and fertilisation with three doses of sludge (160, 320 and 480 kg total N ha^{-1}) compared with two control treatments (mineral and no fertilisation) on soil pH (H_2O), tree growth and botanical composition of the understory in a silvopastoral system under *Pinus radiata* D. Don, fifteen years after the establishment of the experiment in Galicia and twelve years after the last organic fertilisation. Results showed that the tree extractions increased soil acidity mainly due to the high tree density. Therefore, tree clearing is advisable in order to allow the light entrance to the soil, which favours soil organic matter mineralization. Understory biodiversity would also benefit from a minor tree density by improving pasture establishment and microorganism activity.

Keywords: silvopastoral system; liming; fertilisation; soil pH; shadow; understory

Introduction

Galicia (NW Spain) has traditionally presented very acid soils due to its high productivity (extraction) and the high rainfall favouring cations leaching. *Pinus radiata* D. Don is widely used as tree species in the establishment of silvopastoral systems in many areas such as Galicia where it was one of the main species used in afforestation and reforestation made during the 1990s and 2000s. Fast-growing conifers cause an acidifying effect of the soil during their development, since the extraction of nutrients made by this species is usually greater than the hardwoods, with the exception of eucalyptus (Fernández-Núñez 2008). Silvopastoral systems production is usually conditioned by low fertility and high soil acidity limiting nutrient availability to the pasture and trees. Thus, it is advisable to conduct soil management activities such as fertilisation and liming in order to increase fertility and enhance soil pH. Sewage sludge (SS) has been lately adopted in many areas as organic fertiliser due to its organic matter and macronutrient content besides the increase in its production related to the compulsory construction of wastewater treatment plants in areas with low population density established in the Council Directive 91/271/EEC (EU 1991). The biodiversity of the understory can be modified by silvicultural practices as herbaceous cover can be created artificially and maintained by periodic clearing and appropriate fertilisation of the soil (Mosquera-Losada et al. 2005). Soil and aboveground carbon sequestration is an important silvopastoral systems benefit, in addition, a larger carbon content is referable to fast-growing conifer forests such as *Pinus radiata* D. Don. The aim of this study was to evaluate the evolution of soil pH, tree growth and botanical composition of the understory trough the studied period in a silvopastoral system established with *Pinus radiata* D. Don in managed (organic fertilisation and liming) soils.

Materials and methods

The study was located in Pol (Lugo, Galicia, NW Spain) at an altitude of 450 m asl in a plantation of *Pinus radiata* D. Don established in 1993 (1667 trees ha^{-1}). Climate study reflected that vegetation development would be limited by cold during the months of December, January and February (T<7.5 ºC) and by a slight period of drought in the months of June, July and August. In autumn 1997, a randomised block designed experiment was carried out managing 27 experimental plots (9 treatments x 3 replicates). Plots were sown with a *Lolium perenne* L., *Dactylis glomerata* L. and *Trifolium repens* L. pasture mixing after ploughing, mirroring the traditional pastures in the region. At first, all plots were fertilised with 120 kg P_2O_5 ha^{-1} and 200 kg K_2O ha^{-1}. The nine treatments were no fertilisation (NF) and three SS doses (160, 320 and 480 kg total N ha^{-1}) with or without liming applied in 1997 before sowing (2.5 t $CaCO_3$ ha^{-1}). A control mineral treatment (MIN) in the unlimed plots was included (500 kg of 8% N – 24% P_2O_5 – 16% K_2O ha^{-1} from 1998 to 2003). SS was applied in 1998, 1999 and 2000. During the period 1998-2012 soil samples were collected each year in each parcel in December at a soil depth of 25 cm. Soil samples were taken from four points chosen at random within each plot, crossing it in zigzag. The soil pH determination was carried out in water with a 1:2.5 ratio between weight of soil and volume of reagent and a reaction time of 10 minutes. At the beginning and end of 1998, 1999 and 2000, the diameter at the base of the nine central trees of each plot was measured, while at the end of the years 2004, 2006, 2007, 2009, 2011 and 2012 it was the normal diameter (1.30 m height). In all the years in which diameter were measured, the total height of the plots central trees was also measured in order to estimate dominant height. The botanic composition of the pasture was estimated by taking four samples of pasture per plot at random (0.3 × 0.3 m^2) during the spring and winter from 1998 to 2012. In the laboratory, pasture samples were separated into the different species by hand. The data were analysed using ANOVA (proc glm procedure) and means separated by using LSD test, if ANOVA was significant (SAS 2001).

Results

Soil pH in H_2O and tree growth

Soil pH in H_2O was significantly reduced from 1998, when SS and lime treatments were applied, to 4.4 in 2012. Tree height grew steadily from 4 to 19 m. It was observed how soil pH decrease meanwhile tree height increased (Figure 1.).

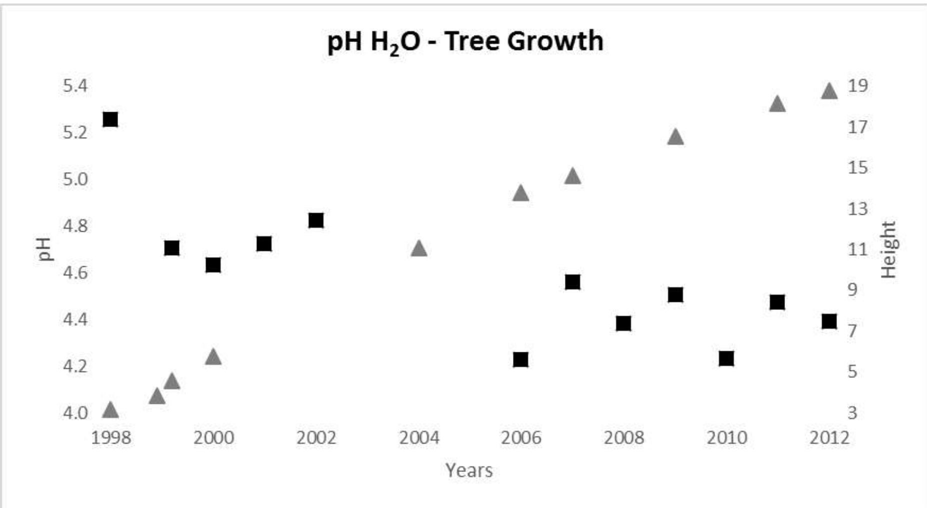

Figure 1: Soil pH in H_2O (■) and tree height growth (▲) evolution during the studied period (1998-2012).

Understory botanical composition

As can be seen in Figure 2, the botanical composition of the understory varied significantly throughout the study period. Needles were the main component of the understory after ten years of the plantation since sown species were disappearing from it. The proportion of needles in the understory was increased as tree height growth raised and replaced year by year *Lolium perenne* L. specially, but also by other herbaceous species and shrubs. *Dactylis glomerata* L. was the better established of the sown species being highly represented in the first half of the study and present in the understory almost until the end of it. A severe reduction in *Dactylis glomerata* L. proportion in the understory was observed from 2003 and again from 2006 matching tree height increase and the consequent needles fall down. *Lolium perenne* L. was well established in the understory during the first couple of years after the sowing but descending in the following years until finally disappearing in 2002. *Trifolium repens* L. was barely established in the first two years and disappeared as early as in 2000.

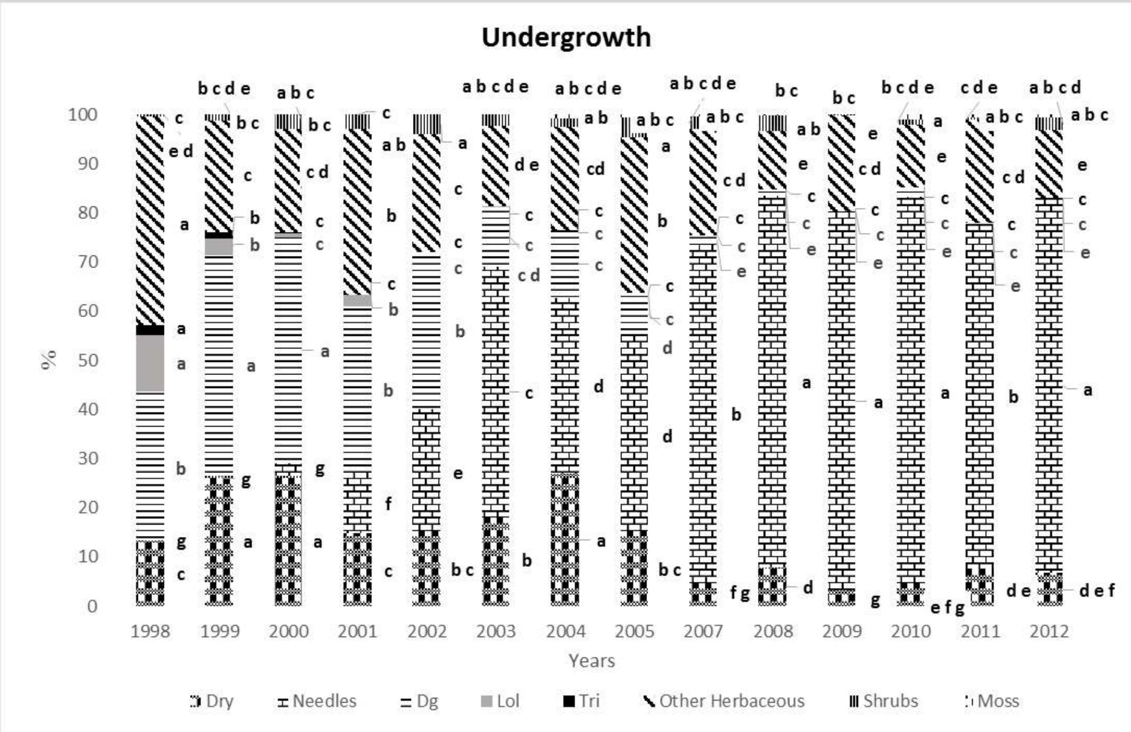

Figure 2: Understory botanical composition throughout the study period (1998-2012), Dg: *Dactylis glomerata* L.; Lol: *Lolium perenne* L.; Tri: *Trifolium repens* L.; Other herbaceous; Shrubs; Dry: senescent material. Different letters indicate significant differences between the years.

Discussion

At the beginning of the experiment the soil pH in H_2O was found on its higher values due to the treatments applied which enhance soil pH and edaphic fertility (Mosquera-Losada et al. 2009a). These results might be explained because of the increase in the mineralisation rate of soil organic matter, the consequent release of nutrients and the ECEC (effective cation exchange capacity) improvement promoted by soil management and treatments applied (Ferreiro-Domínguez et al. 2014). Figure 1 revealed that the pH in H_2O descended through the years meanwhile tree height raised proportionally. It was probably due to the extraction of nutrients and the trees deposition of acidifying material such as needles. On one hand calcium is one of the main components of vegetation that is incorporated in the tree by an intense soil extraction. On the other hand, as seen in Figure 2, the soil deposition of needles became more intense the more the tree grows almost certainly reflecting the limitation of light input to the lower parts of the tree (Mosquera-Losada et al. 2009b; Sibbald et al. 1996). Thus, a reduction in tree density would favour the entrance of light to the understory and consequently an increase in soil temperature promoting the SOM mineralization (Ferreiro-Domínguez 2011) and strengthening an improvement in the understory biodiversity.

Regarding botanical composition of the understory, sown species (especially *Dactylis* glomerata L.) were correctly established the first year of the study. *Lolium perenne* L. almost disappeared four years after being sown while *Trifolium repens* L. just remain as part of the undergrowth a couple years as a consequence of their higher requirements in comparison with *Dactylis glomerata* L. (Grime et al. 2007) concerning soil acidity and shadow conditions caused by the woodland canopy cover besides needles accumulation.

Conclusion

As tree extractions increase soil acidity exacerbated by high tree density and canopy cover that promotes shadow conditions and needles deposition, a reduction trough tree clearing is advisable in order to allow the light entrance to soil, which boost SOM mineralization. Understory biodiversity would also benefit from a minor tree density by improving pasture establishment and microorganism activity.

Acknowledgements

We are grateful to XUNTA DE GALICIA (Consolidation funds and Consellería de Cultura, Educación e Ordenación Universitaria (“Programa de axudas á etapa posdoutoral DOG nº122, 29/06/2016 p.27443, exp: ED481B 2016/0710”)).

References

EU (1991) Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31991L0271 (accessed 13/05/2018).

Fernández-Núñez E (2008) Sistemas silvopastorales establecidos con Pinus radiata D. Don y Betula alba L. en Galicia, productividad, biodiversidad y sumideros de carbono. Servizo de Publicacións e Intercambio Científico. Universidade de Santiago de Compostela, Spain.

Ferreiro-Domínguez N (2011) Efectos sobre la producción y el medio ambiente de la fertilización con lodos de depuradora urbana en sistemas silvopastorales establecidos con Fraxinus excelsior L., Pinus radiata D. Don y Quercus rubra L. Universidade de Santiago de Compostela, Spain.

Ferreiro-Domínguez N, Rigueiro-Rodríguez A, Bianchetto E, Mosquera-Losada MR (2014) Effect of lime and sewage sludge fertilisation on tree and understory interaction in a silvopastoral system. Agric Ecosyst Environ 188: 72–79.

Grime JP, Hodgson JG, Hunt R (2007) Comparative plant ecology : a functional approach to common British species. Castlepoint Press.Dalbeattie, Scotland.

Mosquera-Losada MR, Pinto-Tobalina M, Rigueiro-Rodríguez A (2005) The herbaceous component in temperate silvopastoral systems. CABI, Wallingford, pp. 93–100.

Mosquera-Losada MR, López-Díaz ML, Rigueiro-Rodríguez A (2009a) Zinc and copper availability in herbage and soil of a Pinus radiata silvopastoral system in Northwest Spain after sewage-sludge and lime application. J Plant Nutr Soil Sci 172: 843-850.

Mosquera-Losada MR, Rodríguez-Barreira S, López-Díaz ML, Fernández-Núñez E, Rigueiro-Rodríguez A (2009b) Biodiversity and silvopastoral system use change in very acid soils. Agric Ecosyst Environ 131: 315–324.

SAS (2001) SAS/Stat User’s Guide: Statistics. SAS Institute Inc., Cary, NC, USA.

Sibbald A (1996) Silvopastoral systems on temperate sown pastures: a personal perspective. In: Etienne E (ed) Western European Silvopastoral Systems. INRA edictions, pp. 23-36.